Proximity-field nanoPatterning (PnP)

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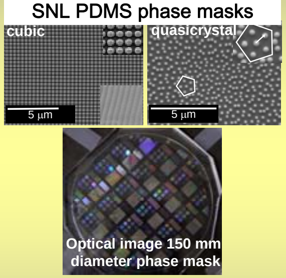
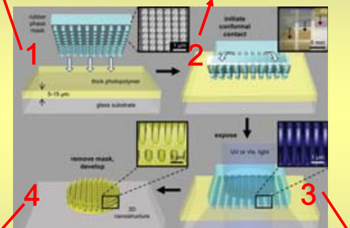
FABRICATION

Silicone rubber phase mask patterned in x, y, z

SNL PDMS phase masks



Conformal contact to photoresist at atomic scale

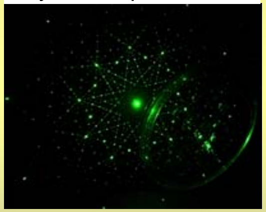


Invented by John A. Rogers, UIUC *PNAS* **101** 12428 (2004)

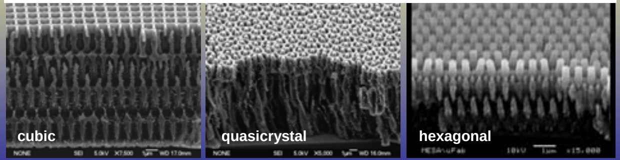
Develop photoresist

Expose photoresist
λ = 365 nm

532 nm light diffracted by 150 mm phase mask



Examples of Various PnP 3D Nanostructure Geometries



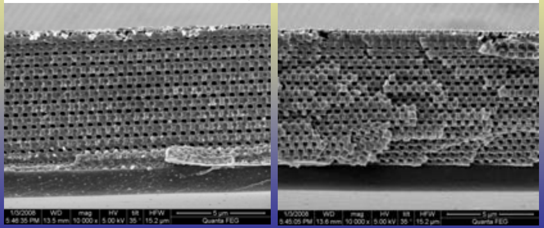
PnP LITHOGRAPHY

- 3D light intensity pattern generated via Abbe diffraction and Talbot imaging principles
- Generate 3D nanometer-scale structures with simple optic and a single lithography cycle
- 3D structures up to 50 µµ thick, feature dimensions 0.5 to 1500 nm
- Fabrication in commercial cleanroom –MESA µFab with scaling to 150 mm
- 1-photon and 2-photon modes
- Engineered design of resultant structures

Atomic Layer Deposition

- Dielectrics: Al_2O_3, ZnO, TiO_2, SiO_2
- Metals: Pt, W
- Graded temperature deposition (patent)
  - no resist deformation
- Increases structural stability
- Modifies surface composition and chemistry

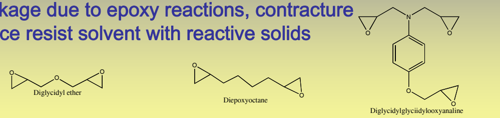
Face-centered cubic PnP structure by 2-photon exposure
Pt-coated by ALD, optical measurements ongoing
Potential photonic lattice



CHEMICAL MODIFICATION

Control resist shrinkage

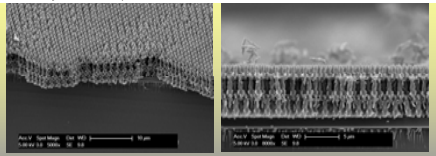
- shrinkage due to epoxy reactions, contracture
- replace resist solvent with reactive solids

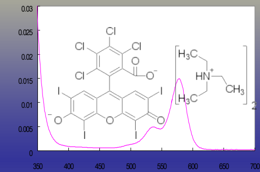


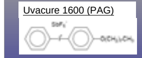
Sensitize Photoresist to ~530 nm for 2-photon mode (Z-Beamlet)

- Rose Bengal (bis(triethylammonium salt))
- UVAcure 1600 (photoacid generator)
- 532 nm, 3.5 W

Cubic geometry exposed at 532 nm, 1 photon mode

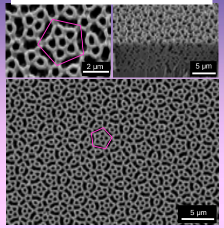






MODELING AND SIMULATION

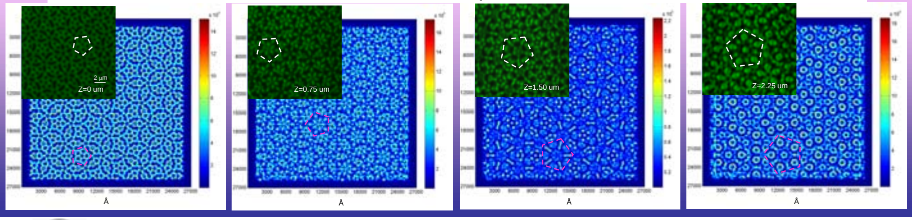
Penrose Quasicrystal 3D resist structure



Simulation and Modeling Methods

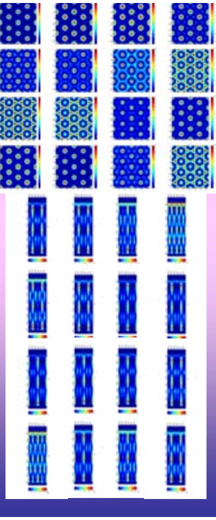
- Forward model inputs mask parameters, calculates 3D light intensity pattern
- Reverse model much more complex: requires iterative optimization
  - desired structure design converted to black/white image
  - input estimated set of period, diameter, and height parameters for phase mask
  - calculate light intensity interference pattern, filter to reveal expected resist burn image
  - compare with desired structure, use integrated optimizer to improve mask parameters
  - cycle again
- Accurate and flexible model allows fabrication of phase mask and 3D nanostructures based on design engineering, not semi-random assembly

Comparison of confocal images of exposed resist (inset) at different depths into the structure to modeled Penrose Quasicrystal 3D nanostructures



The simulation engine is a high performance, OpenMP parallelized FDTD simulator optimized to run on shared memory symmetric multiprocessor (SMP) systems

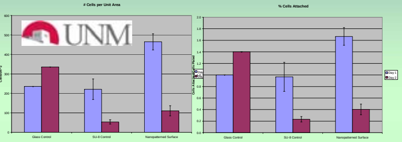
Horizontal (x, y) and Vertical (x, z) Modeled 3D Nanostructures for Hexagonal Geometry



APPLICATIONS

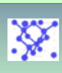
Biochem Surface Interactions

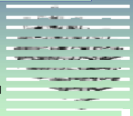
Cells attached 1.5x more on nano-patterns, but poor biocompatibility



- 3D nanostructure fabrication with biocompatible poly(propylene fumarate)
- study cellular focal adhesions & filipodia interactions with ordered nanometer-scale topography
- Affects gene expression, cell function

Photonic Crystals





Yablonovitch et al. *Phys. Rev. Lett.* **67**, 2295 (1991)]

- 3D nanostructure with user-defined, periodic & quasicrystal geometries
- Fabricated in single lithography cycle with simple optic
- No repeated cycles of film deposition/litho/etching
- Fast, scalable, large-area, low-cost

Controllable geometries, variable surface chemistries, high surface : volume ratios suggest: photonics, sensors, storage, catalysis, filtration

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